Scientific Research Associates, inc.

50 Nye Road, P.O. Box 1058
Glastonbury, Connecticut 06033
(203) 659-0333 FAX (203) 633-0676

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Simulation of Preburner Sprays

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Under the present contract a study was made on the characteristics of the sprays of coaxial injectors with particular emphasis on those aspects relevant to the performance of rocket engines. The technical effort was performed primarily by Imperial College of Science and Technology and the details of this effort are contained in the accompanying technical report by Hardalupas and Whitelaw, which forms Vol. II of the present report. The role of Scientific Research Associates was review of material, initial direction of the technical effort and review of all reports.

The present study considered characteristics of sprays under a variety of conditions. Control of these sprays is important as the spray details can control both rocket combustion stability and efficiency. Under the present study Imperial College considered the following:

(1) Measurement of the size and rate of spread of the sprays produced by single coaxial airblast nozzles with axial gaseous stream. The local size, velocity and flux characteristics for a wide range of gas and liquid flowrates were measured and the results were correlated with the conditions of the spray at the nozzle exit.

(2) Examination of the effect of the geometry of single coaxial airblast atomizers on spray characteristics. The gas and liquid tube diameters were varied over a range of values, the liquid tube recess was varied and the shape of the exit of the gaseous jet was varied from straight to converging.

(3) Quantification of the effect of swirl in the gaseous stream on the spray characteristics produced by single coaxial airblast nozzles.

(4) Quantification of the effect of reatomization by impingement of the spray on a flat disc positioned around 200 mm from the nozzle exit. This models spray impingement on the turbopump dome during the startup process of the preburner of the SSME.

(5) Study of the interaction between multiple sprays without and with swirl in their gaseous stream. The spray characteristics of single nozzles were compared with that of three identical nozzles with their axis at a small distance from each other. This study simulates the sprays in the preburner of the SSME, where there are around 260 elements on the faceplate of the combustion chamber.

(6) Design an experimental facility to study the characteristics of sprays at high pressure conditions and at supercritical pressure and temperature for the gas but supercritical pressure and subcritical temperature for the liquid.

In the experiments for single coaxial airblast atomizers an airblast atomizer was constructed and operated at atmospheric pressure. In this setup, air replaced the SSME hydrogen stream and water replaced the SSME liquid oxygen stream. A central tube furnished liquid to the nozzle and the exit plane of this liquid tube could be adjusted to be in the plane of the gaseous tube or recessed. Gaseous flow was supplied by four gas inlets with axes normal to the nozzle. Flow straighteners

were used to remove residual swirl and ensure axisymmetric flow. A wide range of flow conditions were examined for sprays without and with swirl for the gaseous stream. Variations were examined in Reynolds number and parameters based on liquid and gaseous velocities.

Parameters considered include Weber number, gas flow rate and liquid flow rate. In addition, consideration was given to variations in nozzle geometry including gaseous tube diameter, liquid tube diameters, convergence of the gaseous jet exit and recess of the liquid tube. Estimates of relevant physical parameters were made based upon a variety of time scales. These included the gaseous acceleration time, droplet residence time, liquid core characteristic time, characteristic turbulent times, including that of large eddies, and droplet breakup time. Ratios of these times provide local dimensionless parameters which characterize the physical processes. Results were obtained to quantify the effect of swirl in the gaseous stream on spray characteristics. Data was obtained for no swirl, low swirl and high swirl numbers and results included mean velocity of the gas, components of the turbulent stress tensor of the gas, velocity of droplets and droplet size variation in the spray.

In addition, single coaxial jet experiments were performed which included spray impingement on a flat disk; this models flow impingement on the turbopump dome. Details of the impingement process were studied including droplet sizes, and radial and axial droplet velocities in regions well upstream of the disk, in the near disk region and downstream of the disk. Evidence of secondary atomization was found. A study of this secondary atomization was undertaken.

Finally, a study of multiple spray interactions was undertaken for three identical nozzles placed symmetrically. Again, droplet size and velocity fields were measured. The effect of liquid flow rate and swirl was considered and a comparison between the sprays resulting from a single nozzle and that obtained from the three nozzle configuration.

The velocity, diameter, flux and number density of the fuel droplets were measured by a phase-Doppler velocimeter, which comprised transmitting optics based on a rotating grating as beam splitter and frequency shifter and integrated receiving optics which collected the light scattered from the measuring volume in the forward direction at an off-axis scattering angle of 30° on the bisector plane of the two laser beams to ensure that refraction through the droplets dominated the scattered light. The collected light was focused to the center of a 100 μm slit and passed through a mask with three evenly spaced rectangular apertures before reaching the three photodetectors.

The measured size distributions and the mean diameters at each point were based on 20,000 measurements resulting in statistical uncertainties of less than 2% and the sizing accuracy of the instrument was less than 2 μm for droplets larger than 20 μm. The uncertainty is larger for the smaller droplets due to the tolerance of the phase-measuring electronic circuit and the oscillations of the phase shift remaining on the calibration curve of the instrument. Droplet velocities were obtained in 60 size classes, with a 6 μm range in each size class.

Finally, consideration was given to implications of this experimental effort upon the sprays of space shuttle main engines. In particular, the local Weber number was deemed to be the major parameter affecting secondary atomization and estimates of maximum stable diameter in the SSME environment were made. Consideration was given to spray spread rate in the SSME environment and the possibility of secondary atomization and ignition due to impact on the turbopump dome.

Major conclusions of the study focused upon:

- Droplet size characteristics as a function of Weber number.
- Effect of gas flow rate on atomization and spread of spray.
- Effects of nozzle geometry upon atomization.
- Effects of nozzle geometry upon spread.
- Effect of swirl on atomization, spread, recirculation of jet and breakup length.
- Effect of impingement on reatomization.
- Spray interaction of multiple nozzles.